GE Hitachi
Nuclear Energy

Accident Uncertainty Forum
GEH Use of Statistical Methods

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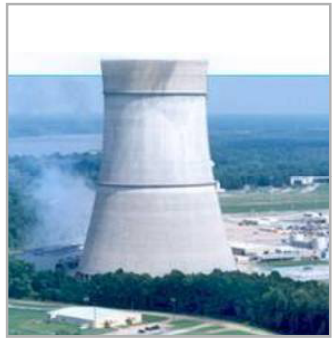
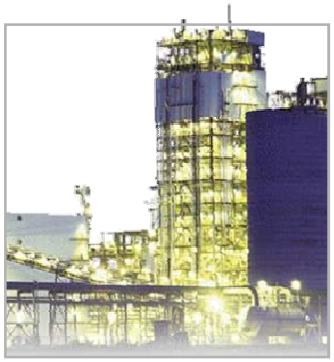
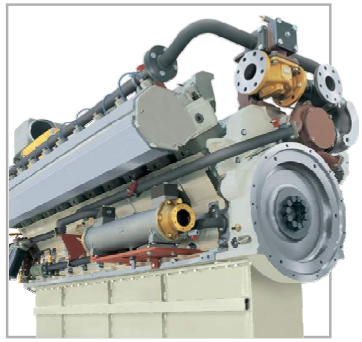

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Outline

- GEH History with Statistical Methods (Pre-CSAU and RG-1.157)
- What the Regulations and RG say
- GEH Use of Statistical Methods (Post-CSAU and RG-1.157)
- GEH Perspective (principal subject)
- Concluding Remarks

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GEH History with Statistical Methods
Pre CSAU and RG 1.157

- "General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Application", NEDE-10958P-A, January 1977
  - Defines Safety Limit Minimum Critical Power Ratio (SLMCPR) such that 99.9% of the fuel rods avoid boiling transition
  - Accounts for uncertainties in total power, pressure, core flow, power distribution and critical power uncertainties.
  - Uncertainties refined in:
    - Methodology and Uncertainties for Safety Limit MCPR Evaluations, NEDC-32601P-A, August 1999
    - Power Distribution Uncertainties for Safety Limit MCPR Evaluations, NEDC-32694P-A, August 1999

GEH History with Statistical Methods
Pre CSAU and RG 1.157

- "Qualification of One-Dimensional Core transient Model for Boiling Water Reactors", NEDE-24154P-A, August 1988
  - Accounts for total power, scram speed and model uncertainties.
    - Model uncertainties originally determined from comparisons to the Peach Bottom 1 turbine trip tests.
    - Model uncertainty confirmed by model sensitivity analyses
    - Impact on ΔCPR/ICPR determined at the 95/95 level
  - Technical specification limits for set points, delays and capabilities.

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GEH History with Statistical Methods
Pre CSAU and RG 1.157

- "The GESTR-LOCA and SAFER Models for the Evaluation of the Loss-of-Coolant Accident", NEDE-23785-1-PA, October 1984
- "SAFER model for Evaluation of Loss-of Coolant Accidents for Jet Pump and non-Jet Pump Plants", NEDE-30996P-A, October 1987
  - Licensing basis PCT calculation in conformance with 10CFR 50 Appendix K
  - Licensing basis PCT confirmed by upper bound PCT
    - Accounts for plant parameters, model uncertainties and scaling
    - Monte Carlo analysis for response surface to bound the 95th percentile of the PCT distribution. 2σ level chosen for the upper bound PCT.

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What the Regulations and RG Say
CSAU and RG 1.157

- B. Boyack et. al., "Quantifying Reactor Safety margins: Application of Code Scaling, Applicability, and Uncertainty Evaluation Methodology to a Large-Break, Loss-of-Coolant Accident", NUREG/CR-5249, December 1989
- Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Regulatory Guide 1.157, "Best Estimate Calculation of Emergency Core Cooling Performance", May 1989
  - RG 1.157 Section 4.4 Statistical Treatment of Overall Calculational Uncertainty
    - "The methodology used to obtain an estimate of the overall calculational uncertainty at the 95% probability limit should be provided and justified."

      No requirement about confidence level
    - "If a normal distribution is selected and justified, the probability limit can be conservatively calculated using two standard deviations. The added conservatism of the two standard deviations compared to the 95th percentile is used to account for the uncertainty in the probability distribution. Other techniques that account for the uncertainty in a more detailed manner may be used. These techniques may require the use of confidence levels, which are not required by the above approach."

      2σ consistent with 95% probability at the 95% confidence level for a single parameter

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What the Regulations and RG Say
RG 1.157

- Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Regulatory Guide 1.157, “Best Estimate Calculation of Emergency Core Cooling Performance”, May 1989
  - RG 1.157 Section 4.4 Statistical Treatment of Overall Calculational Uncertainty
    - “The revised paragraph 50.46(a)(1)(I) requires that it be shown with a high probability that none of the criteria of the paragraph 50.46(b) will be exceeded, and is not limited to the peak cladding temperature criterion. However, since the other criteria are strongly dependent on peak cladding temperature, explicit consideration of the probability of exceeding the other criteria may not be required if it can be demonstrated that meeting the temperature criterion at the 95% probability level ensures with an equal or greater probability that the other criteria will not be exceeded.”
    - No requirement of joint probability of multiple parameters
    - Recognition that the parameters are correlated

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What the Regulations and RG Say
10 CFR 50.46 (a)(1)(i)

(a)(1)(i) Each boiling or pressurized light-water nuclear power reactor fueled with uranium oxide pellets within cylindrical zircaloy or ZIRLO cladding must be provided with an emergency core cooling system (ECCS) that must be designed so that its calculated cooling performance following postulated loss-of-coolant accidents conforms to the criteria set forth in paragraph (b) of this section. ECCS cooling performance must be calculated in accordance with an acceptable evaluation model and must be calculated for a number of postulated loss-of-coolant accidents of different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated. Except as provided in paragraph (a)(1)(ii) of this section, the evaluation model must include sufficient supporting justification to show that the analytical technique realistically describes the behavior of the reactor system during a loss-of-coolant accident. Comparisons to applicable experimental data must be made and uncertainties in the analysis method and inputs must be identified and assessed so that the uncertainty in the calculated results can be estimated. This uncertainty must be accounted for, so that, when the calculated ECCS cooling performance is compared to the criteria set forth in paragraph (b) of this section, there is a high level of probability that the criteria would not be exceeded. Appendix K, Part II Required Documentation, sets forth the documentation requirements for each evaluation model. This section does not apply to a nuclear power reactor facility for which the certifications required under § 50.82(a)(1) have been submitted.

GEH Use of Statistical Methods
Post CSAU and RG 1.157

- "TRACG Application for Anticipated Operational Occurrences (AOO) Transient Analyses", NEDE-32906P-A, Revision 1, April 2003
- "TRACG Application for Anticipated Transient without Scram Overpressure Transient Analyses", NEDE-32906P-A, Supplement 1, November 2003
- "TRACG Application for ESBWR", NEDC-33083P-A, March 2005
- "TRACG Application for ESBWR Stability Analysis", NEDC-33083P-A, Supplement 1, Revision 1 , January 2008
- "ODYSY Application for Stability Licensing Calculations", NEDC-32992P-A, July 2001
- "ODYSY Application for Stability Licensing calculations Including Option I-D and II Long term Solutions",NEDE-33213P, May 2007
- "DSS-CD TRACG Application", NEDE-33147P-A, Revision 2, November 2007
- "TRACG Application for ESBWR Transient Analysis", NEDC-33083P, Supplement 3, December 2007
- These reports generally follow CSAU and RG 1.157 approach
  - Accounts for uncertainties in plant parameters, initial conditions and models
  - Bounding values for critical safety parameters at 95/95 level
  - Order statistics with 59 trials
- Some applications use simplified approach when large margin is available.

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GEH Use of Statistical Methods
Post CSAU and RG 1.157

- Uncertainty Methodology based on 'Random Sampling'
- If a normal distribution can be *defended*, i.e., the distribution is not non-normal, then, use standard deviation (corrected for sample size) to determine the 95th percentile;
- If normality not shown, then, use Order Statistics.
- Sample size: 59 runs

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GEH Perspective
Principal Subject w/o Consensual Resolution

- The main issue is the need for a well-defined criterion: What the regulation requires must be clarified to avoid ambiguity. Define "*high probability*".

- The goal of this forum must be: "to create a consensus where the regulatory uncertainty and review burden would be reduced." This requires "stability, predictability, and consistency in the licensing environment."
  - Clarify the interpretation of the regulatory guides.
  - In recent years, methods relying on non-parametric order statistics were exposed to requirements that exceeded the requirements set forth by the RG 1.157.

- Clarity needed for acceptance of "*best-estimate*" use: Realistic methods combined with uncertainty calculations should suffice to meet the requirements without need for additional *penalties*, creating *hybrid* solutions.
  - A biased sampling is expected even though the ANS Standard on Decay Heat provides the proper uncertainty.

- Once the regulation is clarified the next step is a sound statistical process to demonstrate conformance with the criteria. This could either be in the guide or left to the user.

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GEH Perspective
Concluding Remarks

- Criteria should be independent of a particular technique. Once criteria are set, the correct statistics can tell us how to achieve it. “Regulation” to be kept separate from “Statistics”.
- Approval must be on the methodology, not on particular numbers: enabling updates with justification when new data become available.
- GEH/GNF have invested substantially to their methods and believe the changes must be considered with risk-informed regulation principles in mind.

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